Objective Models for Perceptual Vacuum Cleaner Noise

C. Lee*, Y. Cho**, S. Lee*, J. Park*, D. Hwang**, C. Song** and D. Hur**
* Dept. of Electrical and Electronic Eng. Yonsei Univ., Seoul, South Korea
** Noise & Vibration Team, Center for Product Design Technology, Institute for Advanced Engineering, South Korea

ABSTRACT: - In this paper, we examine objective models to measure perceptual vacuum cleaner noise. We chose fourteen consumer vacuum cleaners and recorded their noise levels in an anechoic-chamber and a real-life apartment. Then, twelve features were computed to measure the perceptual noise levels. In order to obtain the perceptual noise scores, subjective scores were obtained from 100 evaluators using the paired comparison (PC) method. We tested objective models using the twelve features, which showed high correlations with those subjective scores.

Keywords: - objective noise model, vacuum cleaner noise, PC method, perceptual noise level.

1 Introduction

Many home appliances (such as refrigerators, vacuum cleaners, air-conditioners or computers) generate low noise levels. On the other hand, other appliances (such as vacuum cleaners) generate extremely loud noise levels. As consumers become more aware of these noise levels, noise management becomes an important issue in many home appliances [1, 2, 4-7, 10]. For example, efforts have been made to produce quieter vacuum cleaners. In [10], the perceptual noise level of refrigerators was modeled as a linear combination of the twelve features. In this paper, we applied the objective models of [10] to measure the perceptual noise levels of vacuum cleaners. First, we computed the twelve sound quality metrics [9, 10] to characterize noise properties. Then, we measured perceptual noise levels by computing a weighted sum of the twelve sound quality metrics, which will be called as features.

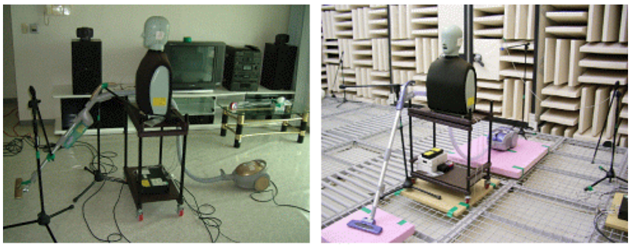
2 Test environments

2.1 Vacuum cleaners

Fourteen commercial vacuum cleaners were tested in this paper. The vacuum cleaners were brand-new and bought specifically for these experiments. Table 1 presents a brief description of the specifications of the vacuum cleaners.

2.2 Recording Environments

We recorded vacuum cleaner noise in a real-life apartment (Fig. 1a) and an anechoic-chamber (Fig. 1b). Table 2 presents a description of the anechoic-chamber and Fig. 2 is a more detailed picture of the anechoic-chamber.



(a) Apartment (b) Anechoic-chamber

Fig. 1. Noise recording environments.

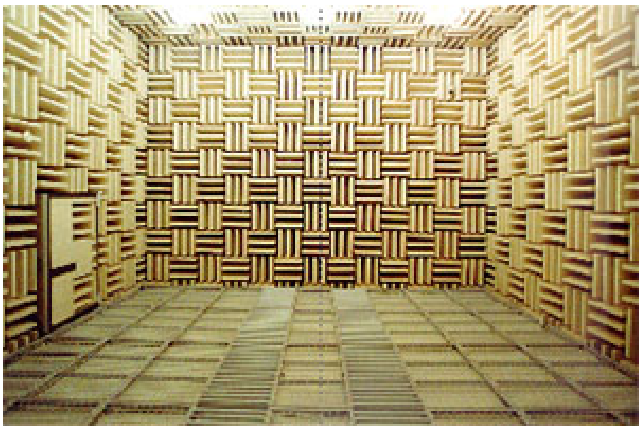


Fig. 2. Anechoic-chamber.

2.3 Recording the noise

Fig. 3 shows how we recorded the vacuum cleaner noise. The microphone was placed between the main body and the cleaning head (or intake port). The distance between the microphone and the main body was about 1*m* and the distance between the microphone and the cleaning head was also about 1*m*. The recording position was chosen to represent real-life use. The microphone was placed 1.3*m* above the floor. Fig. 4 is an example of the spectrum of vacuum cleaner noise.

TABLE 1
DESCRIPTION OF THE FOURTEEN VACUUM CLEANERS

	Capacity (W)
Vac. 1	400
Vac. 2	550
Vac. 3	480
Vac. 4	530
Vac. 5	440
Vac. 6	550
Vac. 7	410
Vac. 8	510
Vac. 9	400
Vac. 10	530
Vac. 11	460
Vac. 12	520
Vac. 13	550
Vac. 14	320

TABLE 2
DESCRIPTION OF THE ANECHOIC-CHAMBER

Size(m)	8.6(L) x 7.8(W) x 7.1(H)
Background Noise	A/C off lower than 15dB(A) A/C On lower 20dB(A)
Cut-off Freq	63Hz

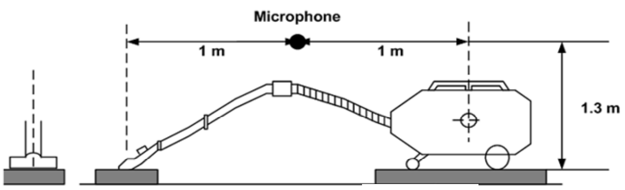


Fig. 3. Recording location of microphone.

In general, noise levels can be computed in terms of energy. This can be obtained as follows:

$$E = \frac{1}{N}\sum_{i=1}^{N}|x[n]|^2$$

where $x[n]$ is a noise signal. Table 3 shows the average energy levels of the fourteen vacuum cleaners. It can be seen that the average energy levels show significant variations. For example, in the anechoic-chamber, the ratio between the quietest and loudest vacuum cleaners is about 30. Fig. 5 shows the spectra of the fourteen vacuum cleaners.

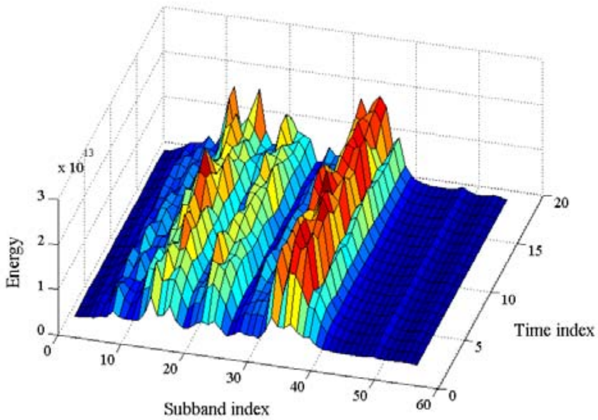
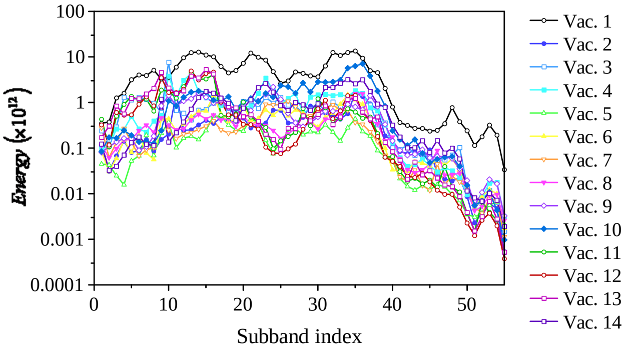


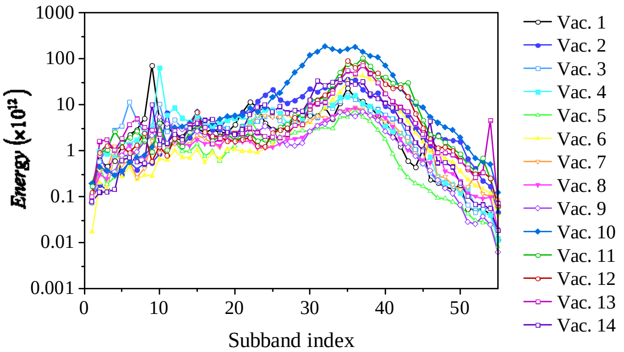
Fig. 4. An example of the spectrum of vacuum cleaner noise.

TABLE 3
ENERGY LEVELS OF THE FOURTEEN VACUUM CLEANERS.

	Energy (1×10^6)	
	Anechoic-chamber	Apartment
Vac. 1	1.990695	2.173755
Vac. 2	0.147551	3.461313
Vac. 3	0.323764	1.843124
Vac. 4	0.385752	2.408618
Vac. 5	0.066111	0.709568
Vac. 6	0.154945	2.448288
Vac. 7	0.129105	1.136902
Vac. 8	0.127688	0.880927
Vac. 9	0.237193	0.932977
Vac. 10	0.544718	15.027170
Vac. 11	0.312142	5.473341
Vac. 12	0.335773	4.625865
Vac. 13	0.373643	3.665228
Vac. 14	0.355296	3.153221



(a) Anechoic-chamber



(b) Apartment

Fig. 5. Spectra of the fourteen vacuum cleaners (using the Bark scale).

3 Subjective testing

We performed a number of subjective tests to obtain perceptual scores. First, we screened potential evaluators with hearing tests. There were 100 evaluators with an age range from the early twenties to the early thirties. The subjective tests were performed using the paired comparison (PC) method [3], in which the noise signals of two vacuum cleaners were played (as shown in Fig. 6). In other words, the first noise (noise 1 or 2) was played for three seconds. After two seconds of silence, the other noise (noise 2 or 1) was also played for three seconds. This procedure was repeated for all the vacuum cleaners. A negative value indicated that the first noise was preferred (less annoying) than the second noise (Fig. 7). Since there are 14 vacuum cleaners, there were 91 pairs. The playing order was randomized. Two subjective tests were conducted: one for the noise recorded in the anechoic-chamber and the other for the noise recorded in the apartment.

4 Modeling vacuum cleaner noises

4.1 Features for objective models

The twelve sound quality metrics (features) were computed from the recorded noise signals of the fourteen vacuum cleaners using commercial software. These twelve features are known to represent noise characteristics [8]. A brief description of the twelve features is provided in Table 4. In this paper, we tested objective models to predict perceptual noise levels that employed two of the twelve features. It appeared that feature 5 (Zwicker Loudness) was the most promising. Thus, we decided to use this feature and we also searched for another feature that provided good performance. The objective model can be represented as a weighted sum of the two features:

$$l_{estimated} = w_1 f_1 + w_2 f_2 \quad (1)$$

where $l_{estimated}$ is the estimated perceptual noise level. In order to find the optimal weights, we used the optimization methods explained in [7].

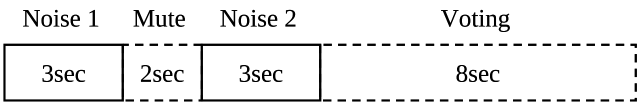


Fig. 6. Playing order in the PC method.

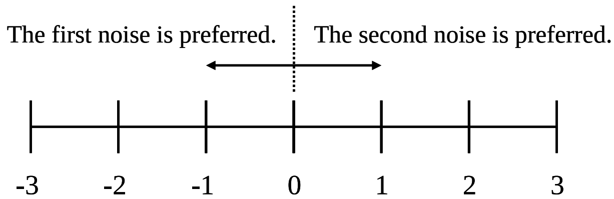


Fig. 7. The paired comparison method.

5 Experiments and performance evaluations

Some of the features that produced good performance along with the Zwicker Loudness feature (Fig. 8) include the A-weighted SPL, Transient Loudness and Speech Interference. When the linear model of equation (1) was applied to the noise recorded in the anechoic-chamber, we obtained similar results. Figs. 9 and 10 show the scatter plot when the objective score was represented as a weighted sum of two features.

TABLE 4
DESCRIPTION OF THE TWELVE FEATURES.

Index	Description of features
0	A-weighted SPL
1	Intelligibility
2	Pref Speech Interference
3	Speech Interference
4	Frame Kurtosis
5	Zwicker Loudness (Sones)
6	Sharpness
7	Transient Loudness (Sones)
8	Transient Sharpness
9	Roughness
10	Fluctuation Strength
11	Tonality

6 Conclusions

In this paper, we tested an objective method to estimate perceptual vacuum cleaner noise levels using some features to represent noise characteristics. Considering the limited number of data points (e.g., the number of vacuum cleaners), we tried to use objective models that used a small number of parameters. Experimental results showed that the method provided good correlations with subjective noise levels.

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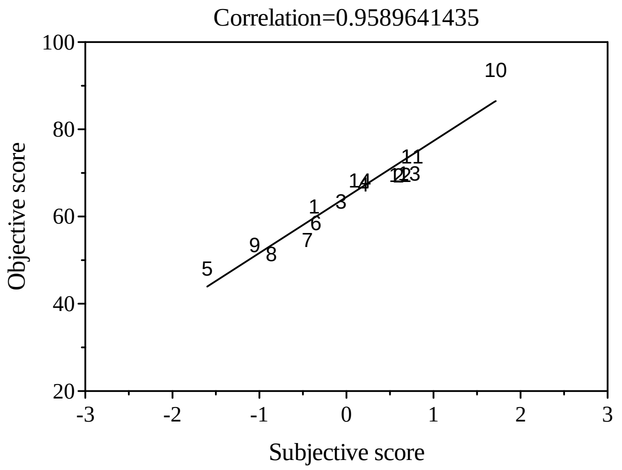
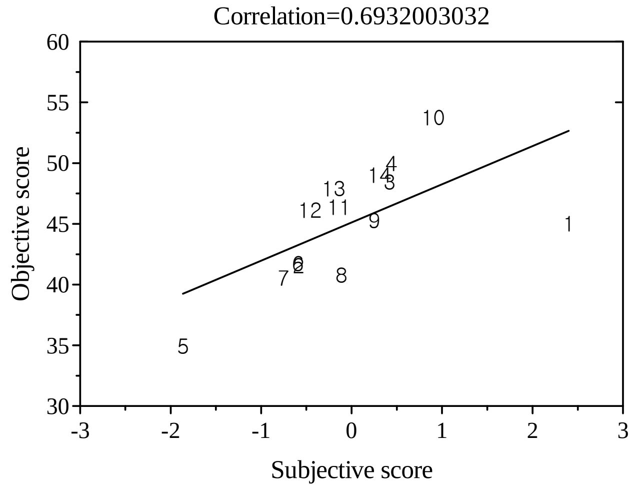
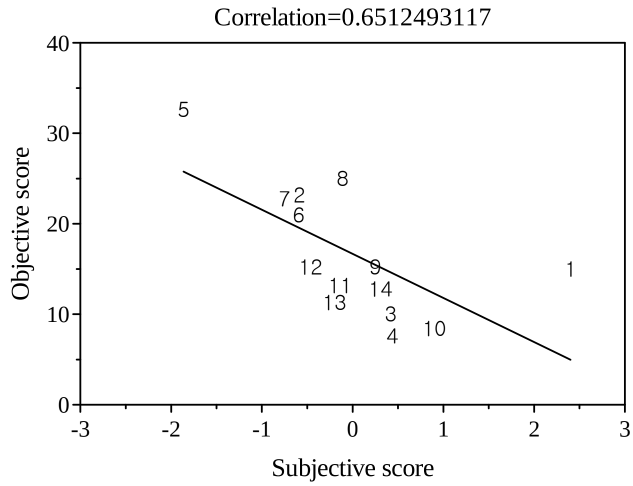


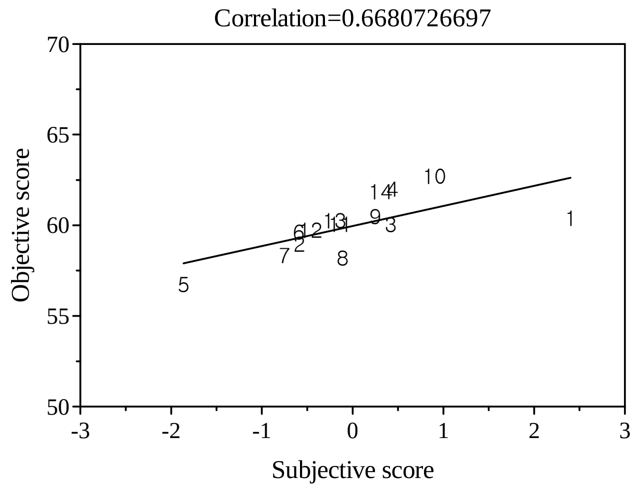
Fig. 8. Scatter plot between subjective and objective score (Zwicker Loudness).



(a) A-weighted SPL & Zwicker Loudness.

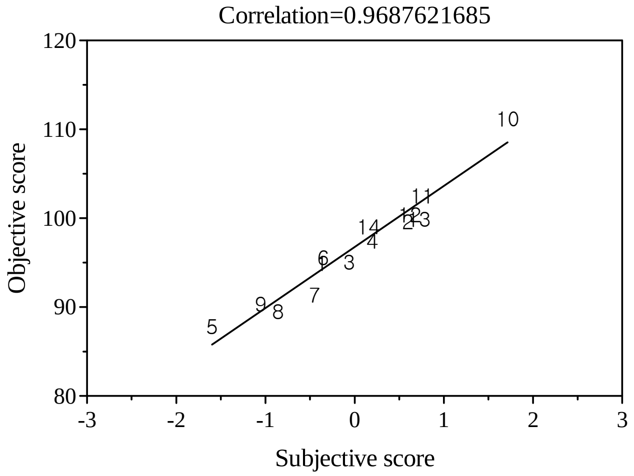


(b) Intelligibility & Zwicker Loudness.

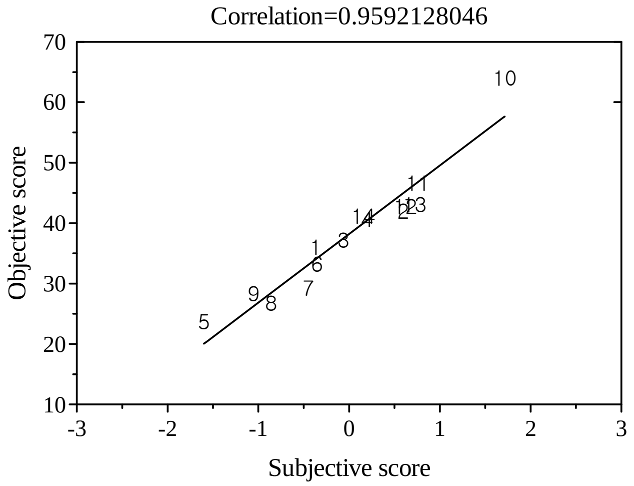


(c) Speech interference & Zwicker Loudness.

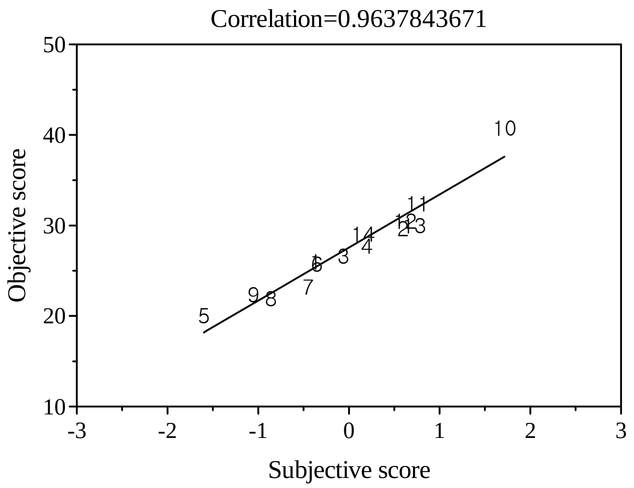
Fig. 9. Scatter plots between subjective and objective scores in the anechoic-chamber.



(a) A-weighted SPL & Zwicker Loudness.



(b) Speech interference & Zwicker Loudness.



(c) Zwicker Loudness & Transient Loudness.

Fig. 10. Scatter plots between subjective and objective scores in the apartment.

References:

[1] A. Takushima, Y. Shinobu, S. Tanaka, M. Eguchi and K. Matsuki, Fan noise reduction of household refrigerator, *IEEE Transactions on Industry Applications*, Vol. 28, No. 2, March-April 1992, pp. 287-292.

[2] C. Chun-Yu and K. Chien-Hsiun, Design and calibration of a noise measurement system, *IEEE Transactions on Instrumentation and Measurement*, Vol. 49, No. 1, Feb. 2000, pp. 77-82.

[3] H. A. David, *The method of paired Comparison*, Lubrecht & Cramer, 1988.

[4] Lord, Gatley, and Evensen, *Noise Control For Engineers*, Krieger Pub. Co., 1981.

[5] D. A. Bies and C. H. Hansen, *Engineering Noise Control: Theory and Practice*, Spon Press, 3rd edition, 2003.

[6] J. Yih-Chyun, Discrete-time method for signal and noise measurement, *IEEE Proc. Instrumentation and Measurement Technology Conference, Integrating Intelligent Instrumentation and Control*, Vol. 1, April 1995, pp. 68-71.

[7] C. Lee and O. Kwon, Objective measurements of video quality using wavelet transform, *Optical Engineering*, Vol. 42, No. 1, 2003, pp. 265-272.

[8] MTS System Co., “MTS Sound Quality Ver. 3.7.5.”

[9] E. Zwicker and H. Fastl, *Psychoacoustics: Facts and Models*, Springer-Verlag, 1999.

[10] C. Lee, Y. Cho, S. Lee, J. Park, D. Hwang and D. Hur, "Modeling Refrigerator Noises," in Proc. IASTED-ASM, pp. 543-547, vol. 522, 2006.